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ANALYSIS AND SYNTHESIS OF DISTRIBUTED-LUMPED-ACTIVE NETWORKS BY DIGITAL COMPUTER

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I. Introduction

The primary goal of this research project has been an investigation of ways in which a modern digital computing facility may be applied to the analysis and synthesis of DLA networks (networks containing Distributed, Lumped and Active elements). This class of networks is of considerable importance in modern filter circuit design. One of the major reasons for this is because the fabrication techniques used to realize integrated circuits readily produce distributed, lumped, and active elements; thus, the DLA class of networks is directly realizable in integrated form. A second major reason for the importance of this class of networks is that DLA networks permit the ready realization of networks with resonant characteristics of the type usually characterized as bandpass and band-elimination, without requiring the use of inductors. The resulting inductorless realizations are attractive since, in general, they are smaller, lighter, and easier to synthesize than their purely lumped RLC counterparts. A final major reason for the importance of the DLA class of networks is that the realization of many of the more commonly required network functions can be made using considerably fewer components than would be required for a purely lumped realization, or for a lumped and active realization.

The advantages of DLA networks are not realized without encountering some disadvantages. This class of network is, in general, not amenable to analysis and synthesis by classical techniques, since it consists of elements modeled by partial differential equations (distributed elements) as well as elements modeled by ordinary differential equations and by algebraic relations (lumped and active elements). Digital computational techniques, however, may be applied to the analysis and synthesis of this class of networks with considerable success, as will be reported in the following sections of this report.

II. The Analysis of DLA Networks

In this section of the report, the development of a general analysis program DLANET (Distributed-Lumped-Active NETwork analysis) for determining the sinusoidal steady-state response of a DLA network is discussed. Of the three types of elements in a DLA network, it is the distributed element which, in general, complicates the analysis procedure. This is the result of the fact that the properties of elements described by partial differential equations, in general, have not been as thoroughly explored as elements described by ordinary differential equations. One of the early efforts made in this research contract was therefore, a literature search to compile an adequate bibliography of references having to do with the properties of distributed networks, and the applications that have been made of them to date. The results of this literature search have been recorded in an annotated bibliography which has been submitted as a separate contract report.[1]

The first matter of importance in analyzing a DLA network is the appropriate representation to be used for the distributed element.

Such a representation must be a compromise between computer program complexity and accurateness of representation of the distributed element. The representation must be general enough to include distributed elements with tapers for which there is no mathematical closed form solution, since such solutions exist for only a relatively few types of taper (uniform, exponential, linear, etc.). In the DLANET program, such generality is achieved by dividing a distributed network into a number of sections of equal length. The resistance and capacitance associated with each section is determined, and the line is approximated by a ladder network of "L" sections consisting of series lumped resistors R_k and shunt lumped capacitors C_k whose sum is equal in value respectively to the total resistance and the total capacitance associated with the distributed line. Provision is included for determining the values of the elements so as to approximate any of the following tapers:

No.	Taper Type	Description
1	Uniform	$R(x)$ and $C(x)$ are constant
2	Exponential	$R(x) = R_0\, e^{ax}$, $C(x) = C_0\, e^{-ax}$
3	Polynomial	$R(x) = R_0\,(1 + p_1x + p_2x^2 + \ldots)$, $C(x) = C_0/(1 + p_1x + p_2x^2 + \ldots)$
4	Discontinuous	The resistors R_k and the capacitors C_k may have any desired explicit values

Several options are available for additional generality, e.g., the exponential taper may be described by specifying the resistance R(0) at the beginning of the line of length L and the resistance R(L) at the end of the line, as well as be specifying the taper coefficient <u>a</u>. In addition, for the polynomial taper option, the program automatically calculates the resistance and capacitance associated with each incremental section of the line when supplied with the coefficients p_i, the total length of the line, the number of sections desired, and the resistance and capacitance per unit length at $x = 0$. Thus, a set of orthogonal polynomials may be used to provide various degrees of accuracy in the representation of a specific taper.

If the transmission matrix for each section of the distributed line is obtained, the transmission matrix for the entire network may be found by multiplying the transmission matrices of the individual sections. The admittance parameters of the network may then be obtained from the transmission parameters. In practice, 20-50 sections may be required, depending on the frequency range and the degree of taper. Actually, the L model for an incremental section of a distributed line is not the only model that can be used. For example, several authors have considered a model based on the use of a T section.[2,3] A report has been prepared tabulating the results of a digital computer comparison of the L section and the T section line for various ranges of frequencies and for various degrees of taper and verifying the validity of this approach to the modeling of distributed elements.[4] The program DLANET contains provisions for incorporating any desired number of distributed elements. If these are identical, the computation of the admittance parameters is made only once. If the distributed elements are different, separate computations are made to determine their admittance parameters.

Once the admittance parameters of the distributed elements are obtained, these are used along with the values of the lumped elements to construct the indefinite admittance matrix of the passive portion of the N + 1 node network. A constraint method is now used to modify the admittance matrix to take account of the effects of any active elements.[5] These may be located anywhere in the network, and are assumed to be of the VCVS type. Finally, using standard techniques,[6] the admittance matrix for the two-port active network is computed. The magnitude and phase of the transfer voltage ratio is then easily obtained. The computational process is completed for each frequency at which the transfer voltage characteristics are required. A plotting capability is included as part of the program to provide magnitude and phase plots of the output quantities.

The analysis program described above is currently operational on the CDC 6400 computer at the University of Arizona. It is a considerably modified and improved version of the program originally described in the Semi-Annual Progress report for this research grant covering the period September 1, 1967 - February 29, 1968. The major improvement is the capability for locating the active element anywhere in the network, and the capability for including as many active elements as desired. The original program permitted only a single active element, and required that it be located at a certain specified point in the network. A paper describing the basic properties of the program has been published.[7] A report describing the program is currently under preparation.[8]

III. The Synthesis of DLA Networks

One of the most promising approaches to the synthesis of DLA networks appears to be the use of optimization techniques. The experience of research workers in this field has indicated that in order to successfully apply optimization techniques to a wide range of problems, it is desirable to have available a varied collection of optimization strategies. To be fully useful, the individual strategies of such a collection must be so designed that any one of them can be applied to the same problem, without requiring that the problem be modified. Thus, the individual optimization strategies can be considered as forming the elements of an optimization software package, in which various logical decisions can be incorporated as an "executive monitor" to successfully apply the different strategies in such a way as to obtain the best final results. As the initial step in setting up a synthesis capability for DLA networks, the formulation of a general problem structure, and the development and testing of a series of optimization strategies has been undertaken. The individual strategies are all applicable interchangeably to any problem which can be put into the specified structure. The result of this research effort has been the development of the computer programs contained in GOSPEL (General Optimization Software Package for ELectrical network synthesis). The general problem structure on which this optimization software package is based is readily capable of several types of application to the synthesis of the DLA network. GOSPEL contains separate subprograms which implement the following optimization strategies: random grid search, random direction and step size search, pattern search, steepest descent, Newton-Raphson, Fletcher-Powell. All of these subprograms have been implemented in a form which permits them to be applied interchangeably to the optimization of a given network. This feature is most desirable, since strategies which may successfully optimize a problem of one type may prove to be ineffective against problems of a different type. Thus, it is of considerable advantage to have available a wide variety of optimization strategies, and GOSPEL provides such a capability. A report has been prepared describing GOSPEL and illustrating in detail the application of the separate optimization strategies of which it is comprised to a series of test problems.[9] Detailed discussions of the component subprograms including flow charts and listings are included in the report. The various components of GOSPEL have been tested on the CDC 6400 computer at the University of Arizona, and are fully operational at this time.

IV. Conclusion

As a result of the research supported by this grant, separate analysis and synthesis tools applicable to the DLA network have been prepared. The analysis of the DLA network is covered by the program DLANET, and the synthesis capability is available through the GOSPEL software package. A research effort is currently underway to combine the analysis techniques for the DLA network with the optimization capability. Preliminary versions of the programming necessary to accomplish this have run successfully, and a general program suitable for the synthesis of DLA networks is currently under development. The details of this program will be covered in future contract reports.

Published Papers and Reports

A list of the papers and reports which have been prepared under this grant during the period September 1, 1967 - August 31, 1968, follows:

"Digital Computer Analysis of Distributed-Lumped-Active Networks", paper by L. P. Huelsman and W. J. Kerwin, published in IEEE Journal of Solid-State Circuits, vol. SC-3, No. 1, Mar. 1968.

"An Algorithm for the Lowpass to Bandpass Transformation", correspondence by L. P. Huelsman, published in the IEEE Transactions on Education, vol. E-11, No. 1, Mar. 1968.

"Digital Computer Modeling of Distributed RC Networks", by L. P. Huelsman and S. P. Johnson, report prepared under NASA Grant NGL-03-002-136, Sept. 1968.

"An Annotated Bibliography for Distributed RC Networks", by S. P. Johnson and L. P. Huelsman, report prepared under NASA Grant NGL-03-002-136, Sept. 1968

"DLANET - A Digital Computer Program for the Analysis of Distributed-Lumped-Active Networks", by L. P. Huelsman and S. P. Johnson, report prepared under NASA Grant NGL-03-002-136, Sept. 1968.

References

1. S. P. Johnson and L. P. Huelsman, An annotated bibliography for distributed RC networks, report prepared under NASA Grant NGL-03-002-136, Sept. 1968.

2. E. N. Protonotarios and O. Wing, Delay and rise time of arbitrarily tapered RC transmission lines, 1965 IEEE International Convention Record, vol. 13, part 7, pp. 1-6.

3. E. C. Bertnolli and C. A. Halijak, Distributed parameter RC network analysis, 1966 IEEE International Convention Record, vol. 14, part 7, pp. 243-249.

4. L. P. Huelsman and S. P. Johnson, Digital computer modeling of distributed RC networks, report prepared under NASA Grant NGL-03-002-136, Sept. 1968.

5. A. Nathan, Matrix analysis of constrained networks, IEEE monograph No. 399E, pp. 98-105, Sept. 1960.

6. L. P. Huelsman, "Circuits, Matrices, and Linear Vector Spaces," McGraw-Hill Book Co., 1963.

7. L. P. Huelsman and W. J. Kerwin, Digital computer analysis of distributed-lumped-active networks, IEEE Journal of Solid-State Circuits, vol. SC-3, No. 1, pp. 26-29, March 1968.

8. L. P. Huelsman and S. P. Johnson, DLANET - A digital computer program for the analysis of distributed-lumped-active networks, Report in preparation.

9. L. P. Huelsman, GOSPEL - A general optimization software package for electrical network design, report prepared under NASA Grant NGL-03-002-136, Sept. 1968.